CSG 15

DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS

Research and Development

Final Project Report

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Project title	Advantages and disadvantages of different break crops in organic grass/arable rotations
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Executive summary (maximum 2 sides A4)

Introduction

Choice of break crops to grow in addition to cereals and the fertility building phase is crucial to both the agronomic and economic success of organic arable rotations. There are four specific functions that a break crop may perform, namely: addition, conservation and cycling of nutrients; pest and/or disease control; weed control and improvement in soil physical characteristics. Individual break crops may perform one or several of these functions. A good break crop must also produce satisfactory yields, be of marketable quality and produce an economic return for the farmer.

Project aims

This project analysed the overall suitability of new break crops by simultaneous assessment of key agronomic, economic and environmental factors. The objectives of the project (in brief) were as follows:

1. To review the scientific literature in order to evaluate known agronomic advantages and disadvantages of 15 potential break crops for organic grass/arable rotations.
2. To evaluate the economic potential of the 15 crops considered to be most suitable as break crops in the agronomic assessment completed under Objective 1.
3. To assess the suitability of nine different break crops (and oat control) grown between winter wheat and spring barley in small scale experimental plots in seven replicated field trials throughout the UK. The data will be used to identify specific problems and opportunities associated with crops.
4. To evaluate a further diversified arable/grass rotation which includes three break crops (potato, carrot and swede) with and without grazing livestock.

5. To assess consumer acceptability, organoleptic characteristics and market potential of crops produced in the large scale field trials described under Objective 4.

Main project findings

- Yields of individual break crop varied greatly between the seven different trials
- Break crop yields were strongly correlated with soil nutrient concentrations
- Cereal yields were affected more by soil fertility status than by preceding break crop
- Over 50% of break crops were deficient in N, P and/or K (according to established values for nutrient concentrations for healthy crops) with N deficiency being the most common. Subsequent cereal crops mostly had adequate nutrient concentrations, although some were deficient in trace elements
- Break crops suffered varying degrees of pest and disease pressure. Hemp and linola had almost no recorded pest/disease damage at any site. Swede, rape and potato were severely affected by pests and/or diseases on most sites
- Different weed burdens were recorded in different break crops. Limited meaningful conclusions can be drawn from this result for five of the crops tested (bean, carrot, potato, swede, sugar beet), due to the different weed control practices at different trial sites on these crops.
- Significantly lower weed burdens were recorded in cereals following hemp and linola.
- The break crops with the highest potential net margin grown in this study were carrot, swede and potato.
- The break crops with the lowest net margins based on 1999 prices were sugar beet and oilseed rape (osr price included an assumed 50% organic premium); organic premiums are now (2002) available for sugar beet.
- Crop quality and yields (and therefore economic returns) from carrot and potato from field scale trials run on a commercial organic farm were much higher than those from small scale plot trials
- All samples of marketable crop (carrot and potato) from the small scale plot trials and field scale trials were classed as acceptable for human consumption under Tesco's current quality standards for organic produce.

Summary of properties of the nine test break crops

Carrot - A crop with very high economic potential but which needs careful attention to weed control if yields are to be maximised. The main potential pest problem which could seriously affect yield is carrot fly. Has a low demand for N and moderate to high requirement for P and K.

Potato - A crop with very high economic potential but also a high risk crop due to the potential for late blight blight to cause high crop losses or total crop failure in some years. The difficulties of controlling blight in potatoes may become much worse when EU approval for copper use is revoked. Other problems including potato cyst nematode, black scurf, powdery and common scab may become more prevalent due to the use of fully organic seed. Has a moderate to high demand for N, P and K.

Swede - A crop with very high economic potential but also a high risk crop due to the potential for attack by a range of pests (including root flies, caterpillars and flea beetle) and diseases (including alternaria, mildew etc.). Has a moderate requirement for N, P and K.

Field bean - Provides good economic returns if average or better yields are obtained. However crop failure and crop losses were common in this project due to pest and disease damage, therefore it is probably a risky organic crop on some sites. No N or P required. Has low K requirements.

Linola - A crop with reasonable economic returns providing average yields are obtained. A useful break crop since it is unrelated to all other common agricultural crops and suffers from no diseases or pests other than birds. Has low N and P requirements and moderate K requirements.

Lupin - Provides reasonable economic returns if average or better yields are obtained. Crop failure was common in this project, but that is probably unusual. The crop suffered from few pests and diseases when growing. Has no N requirements and low requirements for P and K.

Oilseed rape - There is little potential for organic oilseed rape production at present, since the economic returns are low and the risk of loss of crop quality and yield due to many potential pest and disease problems is high. Other oilseed crops, such as linola and sunflower are probably better suited to organic production. Has a high N requirement and low to moderate requirements for P and K.

Hemp - A crop with very low economic potential. However, the limited evidence from practical work and literature reviews associated with this project suggests that it may provide valuable break crop functions in relation to weed control and effects on soil structure. More work is required. Has medium to high requirements for N, P and k.

Sugar beet - The economic potential has improved following the establishment of an organic market. The crop requires careful management to control caterpillars in some sites. Has low requirements for N, P and K.

Implications of findings and future work

This project has provided important information in relation to the agronomic and economic potential of break crops for use in UK organic rotations. Most of the results of this work can be applied to UK organic agriculture now. However, further work is required in order to investigate some of the less well-documented break crop characteristics such as allelopathy (hemp, lupin). It is possible that new varieties bred specifically for organic agriculture may perform better than the varieties used here and additional research is required to investigate this potential. Further, long-term trials are also needed if reliable conclusions are to be reached on the performance of break crops in different UK climatic areas and soil types.

Scientific report (maximum 20 sides A4)

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INTRODUCTION

Organic farming principles dictate that cereals cannot be grown continuously and in practice, they are rarely grown for more than 50 % of the rotation. UK organic grass/arable rotations tend to contain a high proportion of graminaceous and legume crops during the break from cereal production. This contradicts the organic farming standards which encourage the design of rotations based on crop plants from a diversity of plant families and with different rooting patterns in order to prevent the build-up of pest, weed and disease problems specific to graminaceous crops. An additional problem in some stockless grass/arable rotations on light soils is that the maintenance of soil fertility and satisfactory yields depends on substantial inputs of imported fertility in the form of bulky organic manures and composts. This may contravene organic farming standards by creating an unbalanced, non-sustainable production system.

The introduction of additional break crops into organic rotations may provide some solutions to the problems mentioned above. However the introduction of these crops may also create new agronomic, environmental and economic challenges for the farmer. There is a particular requirement for detailed information relating to the following:

- production costs for different break crops (including labour and machinery costs)
- potential markets and current farm gate prices for different break crops
- suitability of different break crop species/ cultivars for production in different areas of the UK
- fertility requirements for break crops (major nutrients and trace elements)
- the main likely pest and disease problems of different break crops and their prevention and control

- the susceptibility of different break crops to weed infestation and suitable prevention and control methods
- the effects of break crops on pests, diseases and weeds in subsequent cereals
- the effects of break crops on soil physical and chemical properties

The beneficial effects of legumes include nitrogen [N] fixation, different root systems compared to graminaceous crops and susceptibility to different pest and disease problems. These differences have been widely studied and legumes have become the most frequently used break crops in organic grass/arable rotations. However, except for vegetables and grain legumes such as peas or faba beans, legumes provide relatively low direct economic returns to the farmer. In addition, the diversity of crops and root systems in grass/arable rotations remains limited when legumes are the only break crops.

Due to the rising demand for an increased range of organic products, a wide variety of crop plants used for human consumption (e.g. carrot, swede, broccoli, onion, potato, soybean, swede, sugar beet), animal feed (e.g. field bean, lupin), oil production (e.g. oilseed rape, borage, linola) and fibre production (e.g. hemp) have become feasible as organic break crops. Many such break crops have very different biology and root systems from graminaceous crops. There is therefore increased potential to maximise the acquisition and recovery and of soil and fertiliser nutrients. Break crops belonging to the legume family would also improve the N balance of the rotation. Non-graminaceous break crops may also substantially reduce the accumulation of weeds, pests and diseases specific to graminaceous crops. Root crops production often involves considerable soil tillage and this may enhance the supply of mineralised N in the system. The inclusion of fodder crops in the system may stimulate the cycling of fertility within the rotation on stocked rotations or between the rotation and local animal production units on stockless systems.

Choice of break crops to grow in addition to cereals and the fertility building phase is crucial to both the agronomic and economic success of organic arable rotations. There are four specific functions that a break crop may perform, namely: addition, conservation and cycling of nutrients; pest and/or disease control; weed control and improvement in soil physical characteristics. Individual break crops may perform one or several of these functions. A good break crop must also produce satisfactory yields, be of marketable quality and produce an economic return for the farmer. For most of the crops mentioned above, there was little available information about their suitability for production over the range of different soil and climatic conditions found throughout the UK prior to this project. Similarly, there was limited information about the performance of potential break crops relative to the four specific functions listed above.

AIMS OF THE PROJECT

This project analysed the overall suitability of new break crops by simultaneous assessment of key agronomic, economic and environmental factors. The main objectives of the project were as follows:

Objective 1 To review the scientific literature in order to evaluate known agronomic advantages and disadvantages of 15 potential break crops for organic grass/arable rotations. Information on the specific requirements of break crops (soil type and fertility, irrigation, machinery, processing facilities), their weed, pest and disease problems and their compatibility with preceding and succeeding crops will be evaluated.

Objective 2 To evaluate the economic potential of the 15 crops considered to be most suitable as break crops in the agronomic assessment completed under Objective 1.

Objective 3 To assess the suitability of nine different break crops (and oat control) grown between winter wheat and spring barley in small scale experimental plots in replicated field trials. Trials will be carried out in parallel in four different climatic and soil conditions throughout the UK. Break crops and the following cereals will be monitored for: (i) soil fertility, aggregate stability, organic matter content and leaching of N and soluble organic N, (ii) disease, pest and weed incidence, (iii) crop nutrient content, yield and quality. The data will be used to identify specific problems associated with crops and allow them to be ranked according to their economic and agronomic potential.

Objective 4 To evaluate a further diversified arable/grass rotation which includes three break crops (potato, carrot and swede) both with and without grazing stock.

Objective 5 To assess consumer acceptability, organoleptic characteristics and market potential of both cereal and vegetable crops produced in the large scale field trials described under Objective 4 and to make a comparison with products from other sources in the UK and overseas.

Achievement of the objectives

Objectives were achieved through the collaboration of a UK-wide project team including scientific, technical and farm staff from Aberdeen University, Scottish Agricultural College (SAC), Welsh Institute of Rural Studies (WIRS), Henry Doubleday Research Association (HDRA), Horticultural Research International (HRI) and the farming company TIO Ltd. Professor Carlo Leifert, who was originally the lead project proposer and project manager, resigned from his post at Aberdeen University in 2000. Dr Audrey Litterick (originally of Aberdeen University, now with Scottish Agricultural College) took over as manager of this project following Professor Leifert's departure. The target dates for achievement of the primary milestones were shifted forward by between 6 months and 1 year (depending on the milestone) because the start of the project was later than originally intended.

AGRONOMIC SUITABILITY OF BREAK CROPS IN SMALL SCALE UK FIELD PLOT TRIALS

Nine of the fifteen break crops evaluated in the economic review submitted to DEFRA in September 1999 (entitled "An economic evaluation of potential organic break crops".) were chosen for further desk and field studies along with oats as a control. The nine break crops were chosen based on their net margins and their reported ability to fulfil useful break crop functions in a wide range of UK climate and soil types.

A detailed literature review was completed on the nine break crops chosen for further study in order to establish optimal agronomic methods for field trials and to determine the advantages and disadvantages associated with the production of each crop. The agronomic characteristics and requirements of the nine crops are summarised in Tables I to IV in Appendix 1. The full literature review is entitled "The agronomic and economic potential of break crops for ley/arable rotations in temperate organic agriculture". The review was published in *Advances in Agronomy* in 2002 and is included here in Appendix 7. Soybean was included in this review paper, since it is an important crop in the United States, where *Advances in Agronomy* is published.

Most break crops serve multiple functions when grown in ley/arable rotations, although the extent to which their main attributes manifest themselves depends on the year, climate, soil type, cultivar or variety and the farming system in question (Altieri, 1987). Following the literature review, the ten crops listed were scored in terms of their financial returns, their value as a pest, disease and/or weed break and their effects on soil structure and nutrient status (Table I).

Method employed in main UK-based field trials

Nine break crops (carrot, potato, swede, field bean, linola, lupin, oilseed rape, hemp and sugar beet) were grown along with oat as a control. The crop varieties used are listed in Appendix 2. Each crop was preceded by and followed by spring barley or winter wheat (Inverness, 1999 only), depending on the rotation at the individual farms. The crops were grown in 12 x 6 m plots (four replicates) in a randomised block design. The same design was used on all seven field trials (see Appendix 2). The crops were tested at four UK locations in 1999 and three in 2000 (Table II). All crops were sown at the normal time for each geographical region/soil type and every attempt was made to carry out similar agronomic practices on each trial site (e.g. weeding, application of organic disease control treatments for potato blight). Crop residues were removed from each plot following harvest. Crop yield, crop quality, pest, weed and disease incidence were recorded in

Table I The value of break crops in organic ley/arable rotations (based on information derived from a literature review carried out prior to the field trials)

	Agronomic benefit[a]				Financial return[b]
Crop	Soil structure	Soil nutrient status	Weed break	Pest/disease break	
Field beans	+	++	-/+	+	+
Lupins	+	++	++	+	-
Soybean	+	++	-/+	+	-
Hemp	++	+	+	+	-
Rape	-/+	-/+	-/+	+	-
Potato	-/+	-	++	+	++
Linola	-/+	-/+	++	+	-
Carrot	-	-	+	+	++
Swede	-	-	-/+	+	++
Sugar beet	-/+	-	-/+	+	-
Winter oats	-/+	-	-	-	

[a]- = detrimental effect; + = small positive benefit; ++ = large positive benefit
[b] Compared with winter oats as standard

Table II Location of field trials in project OF0143

Farm name and year	Trial managers, Location	OS Grid reference
1999/2000[a]		
Frongoch	WIRS, Aberystwyth, Ceredigion, Wales	SN 607 825
Stoughton	HDRA, Leicester, Leicestershire, England	SK 639 029
Culblair	SAC, Dalcross, Inverness, Scotland	NH 764513
Kirton	HRI, Boston, Lincolnshire, England	TF 301 396
2000/2001[b]		
Frongoch	WIRS, Aberystwyth, Ceredigion, Wales	SN 607 825
Elmhurst	HDRA, Coventry, Warwickshire, England	SP 447 842
Murtle	SAC, Bieldside, Aberdeenshire, Scotland	NJ 871 018

[a]Break crops were grown in 1999 followed by cereals in 2000
[b]Break crops were grown in 2000 followed by cereals in 2001

the break crop trials and in the following cereal crops. Soils on all sites were analysed prior to the break crops trials and the effect of each break crop on soil structure, nutrient status and the following cereal crop was also recorded. Further details of the methods used and the results obtained are presented in the relevant sections in the following pages and in Appendices 2 and 3.

Performance of break crops and their effects on subsequent cereals in UK field trials

Materials and methods

Crops were harvested at an appropriate time for each crop in each geographical region, depending on the weather. Detailed field notebooks for each site form part of Appendix 2. Yield was calculated by weighing crop from four quadrats (1 x 1 m^2) from each plot at random and scaling up to a yield in t ha^{-1}. Cereal yields are calculated at 15% moisture. All other yields are of fresh saleable crop weights. Yields of crops in trials were compared to average yields for UK organic crops (recorded in the Economic Evaluation of Potential Organic Break Crops, Appendix 8) or to conventional yields where no average organic yields were available. Plant samples (harvested and non-harvested parts) were taken for nutrient analysis just prior to harvest and were dried and milled prior to analysis for major nutrients and trace elements (see Appendix 3).

Results - Break crop yields

Yields of break crops from the seven UK field trials are summarised in Table III.

Table III Gross yield of break crops (t ha^{-1}) in UK-based field trials

Break crop	Location and year							Mean	Typical yield (organic crops)
	HRI[a] 1999	WIRS[b] 1999	HDRA[c] 1999	SAC[d] 1999	WIRS[b] 2000	HDRA[e] 2000	SAC[f] 2000		
Field bean	0	0	0	7.7	2.0	0	7.2	2.4	3.7
Carrot	58	38	37	17	6	4	38	28	45
Hemp	28	6.0	7.9	0	7.2	7.4	-	8.1	5.5
Linola	0.3	1.6	1.5	0.2	1.6	0	1.2	0.7	1.4
Lupin	0	0	0	0	2.0	0	2.2	0.6	2.5
O. rape	1.0	0.8	1.0	0.7	1.2	0.3	0.6	0.7	2.5
Potato	19	26	36	10	13	20	19	20	35
Sugar beet	32	29	51	11	0	26	18	24	35
Swede	28	38	17	14	0	13	17	18	35
Oat	2.0	1.8	2.7	0	2.3	0	2.2	1.6	3.5
Mean	17	14	15	6	4	6	12		

[a]Lincolnshire, [b]Ceredigion, [c]Leicestershire, [d]Inverness, [e]Warwickshire, [f]Aberdeenshire

General trends in break crop yields - In both years in which break crops were grown (1999 and 2000) the highest yields were distributed across all sites. In 1999, the trial in Inverness produced the highest bean yields, the trial in Lincolnshire produced the highest carrot, hemp and oilseed rape yields, the trial in Ceredigion the highest swede and linola yields and the trial in Leicestershire the highest oat, sugar beet and potato yields. In 2000, the trial in Aberdeenshire produced the highest yields of bean, carrot, swede and lupin. The trial in Ceredigion again produced the highest yields of linola, but also the highest yields of oat and oilseed rape. The site in Warwickshire produced the highest yields of sugar beet, potato and hemp. Break crop yields from the seven trials were correlated with soil nutrient concentrations (P, K and estimated N) at the start of each experiment. Root crops showed a strong N response, sugar beet had a strong Mg response, linola, oilseed rape and oat had strong K responses.

Overall, the highest bean and lupin yields were recorded at the Scottish sites (Inverness and Aberdeenshire). The highest carrot and hemp yields were recorded in Lincolnshire. The highest swede, linola and oilseed rape yields were recorded from the trial at Ceredigion and the trials in Lincolnshire and Leicestershire produced the highest yields of oat, sugar beet and potato. A summary of crop performance at the different sites is provided below in relation to site and weather problems. See section on the effect of break crops on weed, pest and disease incidence for further details on their impact on crop yield and quality.

Field bean - Of the seven sites, only two produced an economically viable bean crop, although yields were very high in comparison to average organic yields at those sites. The trials at Ceredigion, Leicestershire, Warwickshire and Lincolnshire failed due to pest and or disease problems.

Carrot - All seven sites yielded a carrot crop, although the yields at three of the sites were low (Inverness in 1999 and Ceredigion and Warwickshire in 2000).

Hemp - There were significant differences in the yield of hemp between sites. By far the greatest yield was obtained in the trial in Lincolnshire (1999). Such high yields are rarely recorded for hemp in the UK. Yields at Ceredigion (1999 and 2000) and Leicestershire were consistent with average hemp crops. Crop failure at Inverness (1999) was thought to be due to the presence of light, dry soils, which are not suitable for the production of fibre hemp. Crop failure in Warwickshire

(2000) was due to soil capping shortly after sowing. Hemp was not sown in Aberdeenshire (2000) due to the necessary site licence not being granted from the Home Office.

Linola - Of the seven trials, five produced a linola crop, although the yield of crops at Inverness (1999) and Lincolnshire (1999) were well below average for organic linola and were too small to be economically viable. At Inverness, heavy rain at harvest time caused most of the capsules to split and the seeds were shed before harvest. The crop in Warwickshire (2000) failed totally due to poor emergence, soil crusting after sowing and heavy weed infestation.

Lupin - Of the seven sites, only two produced an economically viable lupin crop. A problem was confirmed with the quality and vigour of the seed used in the 1999 trials, since there was total crop failure on all four sites. Of the few plants which did emerge, most were quickly destroyed by pests. There were no significant differences in the yields recorded between the two sites which produced an organic lupin crop of average yield (Aberdeen and Ceredigion, 2000). The crop failed to emerge in Warwickshire (2000) due to soil capping immediately following sowing.

Oilseed rape - All seven trial sites produced an oilseed rape crop, although yields were low in comparison to those expected in conventional systems (oilseed rape is not currently grown as an organic crop in the UK, therefore there are no available average yield figures.)

Potato - All sites produced a potato crop, although the yields were generally lower than average for organic systems. The low yields were thought to have been due in part to a lack of N.

Sugar beet - Six out of the seven sites produced a sugar beet crop, although yields at Inverness (1999) and Aberdeenshire (2000) were very low. Yields close to expected conventional yields were obtained at Lincolnshire and Ceredigion (1999) and a yield well in excess of the conventional average was obtained in Leicestershire (1999).

Swede - Six of the seven sites produced a swede crop, although the yields differed significantly between sites, with only the crops in Lincolnshire and Ceredigion (1999) producing average or above average yields for organic systems.

Oat - The yield of oats at all sites was low in comparison to average yields for organic systems. Two of the seven oat crops failed completely due to pest damage (deer, Inverness, 1999) or to soil capping immediately after sowing (Warwickshire (2000).

<u>Results - Break crop quality</u>
Significant pest, disease and weed problems resulted in loss of crop quality in most crops on most sites, although the percentage of total yield that would have been marketable under current market conditions varied widely between trials. Detailed crop quality assessments and organoleptic tests were carried out on carrot and potato crops from the seven UK plot trials. These are presented below in the section entitled: quality and organoleptic characteristics of break crops. The impact of pests, diseases and weeds is dealt with in more detail in the section entitled: effect of break crops on weed, pest and disease incidence.

Yield and quality of break crops was also affected by the soil available nutrients. The data from this part of the project is extremely varied and complex and is therefore difficult to summarise in a short report of this type. The data on soil nutrient concentrations and their relationships with crop quality, yield and nutrient concentrations in break crops is dealt with in detail in a PhD thesis which is fully referenced in Appendix 3. The data will also be published shortly in the refereed literature (see abstract in Appendix 5). Details of the break crops which were found to be nutrient deficient in trials (following consultation with a range of literature sources on acceptable and deficient crop nutrient concentrations) are summarised in Table IV. Between 62 and 80% of all crops at all sites were deficient in N. Between 25 and 63% of all crops at all sites were deficient in P. Between 14 and 63% of all crops at all sites were deficient in K.

<u>Results - cereal yields</u>
There were significant differences between the yields of spring barley crops grown in the different trials (Table V). However, there were no significant differences between the yield of cereals grown following different break crops. The yields of cereals were correlated with soil nutrient concentrations, but not with previous crop. Wheat and barley yields were strongly influenced by the concentrations of soil N and P.

Table IV Numbers of nutrient deficient break crops at seven sites across the UK

Trial	Total no. of crops	No. of crops at each site		
		N deficient	P deficient	K deficient
1999/2000				
Ceredigion	7	5	4	4
Leicestershire	7	5	4	2
Inverness	7	6	2	1
Lincolnshire	8	5	5	5
2000/2001				
Ceredigion	8	6	5	3
Warwickshire	5	4	5	2
Aberdeenshire	8	5	2	2

Results - cereal quality

Cereal grain nutrient concentrations were in general adequate for the major nutrients. However, grain S, Cu, Mn and Zn was deficient at some or all sites. S deficiency occurred only at the site in Lincolnshire (2000). Zn deficiency in cereal grain occurred at the same site and also in Aberdeenshire (2001). Cereal grain Mn was deficient in crops from all sites. Cereal grain Cu was deficient in all treatments at the Aberdeenshire site (2001).

Table V Yield of cereals[a] following break crops (t ha^{-1}) in UK-based field trials

Break crop	Location and year							
	HRI[b] 2000	WIRS[c] 2000	HDRA[c] 2000	SAC[e] 2000	WIRS[c] 2001	HDRAf[b] 2001	SAC[g] 2001	Mean[h]
Field bean	5.8	5.2	3.0	3.5	3.3	2.0	2.1	3.8
Carrot	6.0	4.4	4.0	2.3	2.9	2.3	1.8	3.7
Hemp	6.0	4.1	2.5	2.4	3.6	2.5	2.5	3.5
Linola	6.6	4.8	2.6	2.2	3.7	2.3	2.2	3.7
Lupin	6.1	4.2	2.7	2.1	3.4	2.5	1.7	3.5
O. rape	6.0	5.5	2.3	3.4	3.3	2.6	1.9	3.9
Potato	5.8	5.5	3.2	2.8	2.2	1.8	1.9	3.6
Sugar beet	5.5	6.0	2.3	2.7	3.3	1.8	2.3	3.6
Swede	6.0	4.2	1.7	2.7	3.4	1.9	1.7	3.3
Oat	6.0	4.8	2.5	3.3	3.5	2.5	1.9	3.8
Mean	6.0	4.9	2.7	2.7	3.3	2.2	2.0	

[a]spring barley was planted at all sites except Inverness (2000) where winter wheat was planted
[b]Lincolnshire, [c]Ceredigion, [d]Leicestershire, [e]Inverness, [f]Warwickshire, [g]Aberdeenshire
[h]mean yield of spring barley crops only, winter wheat excluded

Discussion

The yields of break crops grown in the seven field plot trials varied widely from the average yields reported in the economic review. Some (e.g. hemp in Lincolnshire, 1999 and field bean in Inverness, 1999 and Aberdeenshire, 2000) were considerably higher than reported average organic yields. Others such as the oats (most sites), sugar beet (Inverness, 1999) and carrot (Warwickshire, 2000) were much lower than reported average organic yields. Many of the crops were found to be deficient in major nutrients, which suggests that lack of these nutrients was depressing yield on some sites. The seven field trials have shown what is possible in terms of break crop yields, but they have also highlighted the problems which can occur due to nutrient deficient soils and as a result of pests, diseases and weeds. It is often the case that pest problems and sometimes foliar disease problems can be exacerbated in small plot trials of this type.

Weeds also caused serious problems in some crops (see later section on the effect of break crops on weed, pest and disease incidence). Mechanical weed control proved impossible due to the diverse nature of the crops grown and hand weeding proved expensive. Weeds therefore probably had a greater (negative) impact on crop yield than they normally would in larger fields of the test crops where weed control measures could be tailored to the crop in question.

There were no significant effects of break crops on the quality or yield of the following cereal crops on any of the seven sites. This result conflicts with the work of several others who have found that a range of break crops, including some of those tested, can affect the quality and yield of subsequent cereals (Robson *et al.*, 2002). The observed lack of yield response to previous crop may have been due to the fact that the trial plots were left fallow over the winter: leaching of nutrients (especially nitrate) may have occurred, particularly in high rainfall areas such as that at Ceredigion and in light soils such as that at Inverness.

Effect of break crops on soils in UK field trials

Materials and methods

Soils on all sites were analysed for major nutrients and trace elements before and after the break crops trials and after the following cereal crops. Soil organic matter (OM) levels, soil pH and soil structure (aggregate stability) were also recorded for each soil sample. It was initially intended to assess leaching of nitrate and organic N, but this was not done due to lack of resources within the project.

Results

The data on soil nutrient concentrations at different points in the trials, soil nutrient concentrations in break crops and cereals and the relationships between them is extremely complex and varied. It is therefore difficult to summarise in this short report. It is discussed in detail in the PhD thesis (Appendix 3) and will be published shortly (see abstract in Appendix 5). An example of the data (K in the Aberdeenshire trials) is given below (Table VI) to illustrate the nature of the data and conclusions drawn. Apart from this example, only the main conclusions of this part of the study are reported here.

Table VI Extractable soil K concentrations (kg ha^{-1}, before and after break crops and after following cereals) and K offtake (kg ha^{-1}) by break crops and cereals in Aberdeenshire trials in 2000/2001.

Crop	Mean soil K before break crop	Mean total K offtake by break crop	Mean soil K after break crop	Mean total K offtake by cereal crop	Mean soil K after cereal
Bean	222^{a}	23^{d}	239^{b}	7.0^{a}	170^{a}
Carrot	185^{a}	119^{d}	182^{a}	6.8^{a}	163^{a}
Hemp	No crop	-	-	-	-
Linola	197^{a}	47^{b}	203^{b}	8.6^{a}	131^{a}
Lupin	234^{a}	10^{a}	239^{b}	6.4^{a}	208^{a}
O. rape	277^{a}	49^{b}	220^{b}	7.2^{a}	173^{a}
Potato	214^{a}	88^{c}	207^{b}	6.9^{a}	166^{a}
S. beet	248^{a}	8^{a}	225^{b}	6.1^{a}	181^{a}
Swede	237^{a}	5^{a}	253^{b}	6.9^{a}	188^{a}
Oat	293^{a}	10^{a}	267^{c}	7.2^{a}	199^{a}

[a] Different superscript letters indicate significant differences

There were no differences between soil K concentrations in different plots at the start of the experiment. After the break crops were harvested, there were treatment differences between the K concentrations of soils. For example, K concentrations in soils after carrot were significantly lower than in soils after other crops and K concentrations in soils after linola were significantly higher than in soils after other crops. There were no differences recorded in soil K after the harvest of cereals which followed different break crops. Soil K significantly decreased following bean, sugar beet, lupin and oilseed rape. There were differences ($P < 0.001$) between K offtake by break crops, with carrot, swede and potato crops removing significantly more K per hectare than other crops. There were no differences in K offtake between cereal crops which were preceded by different break crops.

The main conclusions from this part of the study are as follows. In general, the soil nutrient concentrations decreased over the soil sampling period (from pre-break crops to post cereals) on all trial sites. The soil pH and the soil organic matter levels also tended to decrease, although there were exceptions to that general rule. There were usually no significant differences between soil nutrient status on different plots prior to the experiments at the seven sites. There were usually significant differences between nutrient offtake of different break crops. There were occasional differences in concentrations of some soil nutrients at some sites when the soil was sampled post break crops/pre-cereals. Nutrient offtake of cereals following different break crops were generally similar and there were no significant differences between soil nutrient concentrations after the harvest of cereals which had followed different break crops. No changes in soil physical characteristics were recorded following break crops or cereals in the trials.

Discussion

Break crops can contribute to soil fertility in five main ways. Firstly through N fixation, secondly through re-incorporation and recycling of nutrients, thirdly through reduction of nutrient losses, fourthly through the incorporation of soil organic matter and lastly through improvements in soil structure. All of the break crops planted in this study have been reported to have beneficial effects on some aspect of soil quality or fertility (Robson *et al.*, 2002).

Nutrient concentrations in the harvested crop (roots, tubers, grain etc.) and the non-harvested parts (such as straw, stalks, leaves etc.) were recorded for all crops at all sites and this information will be useful when developing nutrient budgets for crops. However, this study was not ideally designed for examining potential break crop effects on soil quality, soil nutrients and organic matter, since the crop residues were not incorporated into the soil after harvest as they often would be on organic farms. The only parts of the break crops which were returned to the soil were the roots (bean, hemp, oat, barley, lupin, oilseed rape, linola plus small amounts of the other crops) and the stubble/lower plant parts (bean, hemp, oat, barley, lupin, oilseed rape, linola). The effects of the test break crops and following cereals on soils reflect only the extent to which the break crop residues were returned to the soil. The results may have been very different if all the non-saleable crop parts were returned to the soil following harvest.

Effect of break crops on weed, pest and disease incidence in UK field trials

Materials and methods

All break crops (1999 and 2000) and cereals (2000 and 2001) on all seven sites were assessed for the presence of pests and diseases on two occasions during the cropping season in late June and mid August. Where pest damage or disease was light, no quantitative assessments were made. When pest damage or disease was serious and likely to limit crop yield and/or quality, qualitative assessments were made using established disease assessment scales or scales designed for the purpose. Crops were weeded according to the protocol and field notebooks in Appendix 2. Weed burdens were assessed and weed species were recorded on each site on the same dates as the pest and disease assessments were made. All assessments on all sites were made by the same person.

Results - pests and diseases in break crops

The results recorded in Table VII represent a very brief summary of what is a complex and detailed dataset. The impact of pests, diseases and weeds on the quality and yield of break crops is dealt with in more detail in the PhD thesis (see Appendix 3) and will be discussed more fully in the planned paper (see abstract in Appendix 5).

The control oat crops in general grew poorly and relatively low yields were obtained. Low levels of powdery mildew were observed in the oats grown in Aberdeenshire in 2000 and low levels of rust were found in the oats grown in Ceredigion in 2000, but these diseases were not thought to affect yield. Where pests were present towards crop maturity (Ceredigion, finches both years and Inverness, deer, 1999) yield was badly affected.

Hemp suffered no pest or disease attack at any of the seven sites.

Table VII Pests and diseases recorded on break crops at seven UK-based field trials

	Trial site						
Break crop	**HRI[a] 1999**	**WIRS[b] 1999**	**HDRA[c] 1999**	**SAC[d] 1999**	**WIRS[b] 2000**	**HDRA[e] 2000**	**SAC[f] 2000**
Bean	pigeons, rooks, choc. spot[g]	pigeons, rooks, choc. spot	pigeons, rooks	choc. spot, pea/bean weevil[h], rust[i]	choc. spot, pea/bean weevil, rust	no crop	rust
Carrot	-	carrot fly[j]	virus	carrot fly	-	rabbit	-
Hemp	-	-	-	-	-	-	no crop
Linola	-	-	-	-	-	-	-
Lupin	-	pigeons, rooks	pigeons, pea/bean weevil	-	-	no crop	-
Oilseed rape	pigeons	pigeons, rooks, finches	pigeons, flea beetle[k]	alternaria[l], botrytis[m], pollen beetle[n], cabbage seed weevil[o]	flea beetle, alternaria, finches	powdery mildew[p], flea beetle	powdery mildew
Potato	late blight[q], blackleg[r]	late blight, blackleg	late blight, blackleg	late blight, blackleg	late blight, blackleg	late blight	late blight, blackleg
Sugar beet	caterpillars[s]	caterpillars	slugs[t]	-	caterpillars	-	caterpillars
Swede	alternaria, powdery mildew, aphids[u]	caterpillars	flea beetle, pigeons	caterpillars, rabbits, pigeons	caterpillars, flea beetle	caterpillarsflea beetle	caterpillars, flea beetle
Oat	-	finches	-	deer	rust[v], finches	no crop	powdery mildew[w]

[a]Lincolnshire, [b]Ceredigion, [c]Leicestershire, [d]Inverness, [e]Warwickshire, [f]Aberdeenshire, [g]chocolate spot is caused by the fungus *Botrytis fabae;* [h]*Sitonia lineatus*; [i]bean rust is caused by the fungus *Uromyces appendiculatus*; [j]*Psila rosae*; ; [k]*Psylliodes chrysocephala* ; [l]leaf spot on oilseed rape is caused by *Alternaria brassicae*; ; [m]Botrytis or grey mould is caused by *Botrytis cinerea*; [n]*Melligethes* species; [o]*Ceutorhynchus assimilis*; [p]powdery mildew on oilseed rape is caused by the fungus *Erysiphe cruciferae*; [q]late blight on potato is caused by the fungus *Phytophthora infestans*; [r]blackleg on potato is caused by the bacterium *Erwinia carotovora*; [s]various *Pieris* species; [t]various species including *Deroceras reticulatum*;; [u]various species including *Brevicoryne brassicae and Myzus* species; [v]rust on oats is caused by *Puccinia* species; [w]powdery mildew on oat is caused by *Erysiphe graminis*

Linola suffered from no pests and diseases other than birds. In Lincolnshire, the crop failed to recover from early bird damage at sowing. The seeds from the crop in Leicestershire (1999) were eaten by birds just prior to harvest and there was no measurable yield.

Field beans were affected by pests and/or diseases at all sites. The main bean pest problems occurred shortly after sowing, when seed which was not sown deeply enough was dug up and eaten by birds. This caused poor plant establishment and

greatly reduced yields at all sites except Inverness in 1999. Weevils caused small losses in crop quality and yield in two sites and chocolate spot and/or bean rust caused losses (mainly in crop quality rather than yield) in most sites.
Carrots had no disease problems during the growing season apart from a small patch of virus in a limited area in one plot at Leicestershire (1999). Carrot fly caused slight reductions in crop quality in the trials at Ceredigion and Inverness (1999) and rabbits caused slight damage at the trial in Warwickshire (2000), although it is not thought that they affected the yield.

The lupin seed was dug up and eaten shortly after sowing by birds at Ceredigion and Leicestershire (1999). and pea and bean weevil caused further damage on the few remaining plants in Leicestershire. No pests or diseases were recorded on the lupin crops at Ceredigion and Warwickshire in 2000.

Oilseed rape was affected badly by pests (birds and beetles) and diseases (mildew and alternaria) in all trials. Crop yield and quality were affected in all trials.

Potato was affected by low levels of blackleg (between one and five plants per plot) in all trials in both years. This problem was almost certainly seed-borne, since few of the fields used in trials had been used recently for potato production. Yield and crop quality were both affected. Late blight also severely affected the yield and quality of potatoes in every trial.

Sugar beet was badly affected by caterpillars and/or slugs in most trials. In some cases the crops grew through the damage, in other cases, the yield was affected.

Swede crops were badly affected by pests (including caterpillars, aphids, flea beetle, rabbits and pigeons) on all sites and yield and crop quality were badly affected in some cases. Diseases including alternaria and powdery mildew were recorded in the trial in Lincolnshire (1999), but these probably did not affect crop quality or yield.

<u>Results - pests and diseases in cereals</u>
There were few diseases and no pests recorded in the cereals following the break crops in the seven trials. There were no significant differences in cereal disease levels between sites or between preceding crops.

<u>Results - weeds in break crops</u>
There were significant differences between weed burdens in different sites (Table VIII). The weed burden was lowest in the trials at Warwickshire and Aberdeenshire (2000) and highest at Ceredigion (2000). There were significant differences between weed burdens in different crops. Weed burdens were lowest in hemp, potato and carrot and highest in lupin.

<u>Results - weeds in cereals</u>
There were significant differences between weed burdens in cereals at the different sites (Table IX). The weed burden was lowest in the trials at Ceredigion (2000) and Aberdeenshire (2001) and highest at Inverness (2000). There were significant differences between weed burdens in cereals following different break crops. Weed burdens were lowest in hemp and linola and highest in bean and carrot.

<u>Discussion</u>
It is difficult to draw detailed, meaningful conclusions on pest, weed and disease problems in break crops and following cereals from only two years of field trials of this type. Firstly, the incidence and severity of pest/disease epidemics is often very different in small scale plot trials from that in field-scale commercial cropping. Secondly, the incidence and severity of weed, pest and disease problems is highly dependent on (variable UK) weather conditions, topography, soil type and the farming system in question. In addition, although all trials were set up on prepared land which was visually weed free, the weed seed burden and number of fragments of perennial weeds would have differed between sites. Every effort was made to standardise the crop husbandry methods used in the seven field trials, but differences between methods still occurred between trials.

However, this work has provided useful general information on pests and diseases in break crops. Hemp and linola were easy to grow organically from a crop health point of view, since they suffer from few pests and diseases (apart from bird damage on two linola crops). The other eight crops grown were all susceptible to pest and disease attack to some extent and oilseed rape, potatoes and carrots will pose particular challenges to the large scale organic grower.

Table VIII Severity of weed infestation[a] in break crops at seven UK-based field trials

Break crop	HRI[b] 1999	WIRS[c] 1999	HDRA[d] 1999	SAC[e] 1999	WIRS[c] 2000	HDRA[f] 2000	SAC[g] 2000	Mean
	Trial site							
Bean	3.0	6.0	6.0	2.6	7.0	1.0	2.5	4.0
Carrot	3.0	1.5	2.0	5.5	4.5	0.5	3.0	2.9
Hemp	0.0	2.0	2.0	5.5	4.8	1.0	-	2.6
Linola	5.0	4.0	4.0	4.5	5.5	1.5	2.0	3.8
Lupin	5.0	6.5	5.0	6.0	5.0	1.0	1.3	4.5
O. rape	1.5	2.5	3.0	4.0	7.0	2.0	2.8	3.3
Potato	1.0	3.0	1.0	4.0	7.0	1.5	1.0	2.6
S. beet	3.0	2.5	2.0	3.5	7.0	2.0	3.8	3.4
Swede	5.0	2.0	5.0	2.5	4.0	1.0	3.0	3.2
Oat	2.0	4.0	4.5	4.0	3.0	1.5	3.0	3.1
Mean	3.1	3.4	4.0	4.2	5.5	1.3	2.5	

[a]Weed severity index: 0=no weeds, 1=very light weed growth, 2=light weed growth, 3=light to moderate weed growth, 4=moderate weed growth, 5=moderate to heavy weed growth, 6=heavy weed growth, 7=very heavy weed growth
[b]Lincolnshire, [c] Ceredigion, [d]Leicestershire, [e]Inverness, [f]Warwickshire, [g]Aberdeenshire

Table IX Percentage weed cover in cereals following break crops at seven UK-based field trials

Break crop	HRI[a] 2000	WIRS[b] 2000	HDRA[c] 2000	SAC[d] 2000	WIRS[b] 2001	HDRA[e] 2001	SAC[f] 2001	Mean
	Trial site							
Bean	No data	34	62	63	31	37	15	40
Carrot	"	2	71	70	40	49	7	40
Hemp	"	12	6	34	19	33	8	19
Linola	"	2	9	32	31	24	9	18
Lupin	"	42	27	24	23	41	12	28
O. rape	"	6	26	30	28	26	17	22
Potato	"	4	46	75	40	41	3	35
S. beet	"	12	44	34	36	49	10	31
Swede	"	16	47	36	31	46	10	31
Oat	"	6	26	30	28	26	17	22
Mean	"	14	36	43	31	37	11	

[a]Lincolnshire, [b] Ceredigion, [c]Leicestershire, [d]Inverness, [e]Warwickshire, [f]Aberdeenshire

The weed incidence data is difficult to interpret because each site was managed slightly differently, despite the fact that a common weeding protocol was drawn up. Some sites were weeded later (in relation to crop growth stage) than others and this resulted in different weed burdens in crops. This meant that the weed burden in each crop was a function of the time and efficiency of hand weeding as well as the weather, soil type, soil fertility etc. It is highly likely that weeds in the following cereals were affected not only by preceding break crop, but also by the efficiency and timing of hand weeding in the preceding break crop. Since different UK sites will always be staffed by different teams, an experiment of this type will always be subject to variation unless weeding methods are standardised through the use of machinery used at specific crop growth stages.

Some clear trends did emerge from the weed assessments and these may be worth further investigation. The weed burdens in hemp and potato were generally lower than in other crops. This may be due to the rapid production of dense foliage, but allelopathic effects against weeds are also possible with the hemp (Bosca & Karus, 1998).The weed burden in carrot crops at some sites was lower than the mean site weed burden, but this was due to careful hand weeding rather than to any weed smothering effect by the crop. The weed burdens in cereal crops following either hemp or linola were significantly lower than those in cereals following other break crops. This effect may be due to the prevention of weed growth and weed seed production in the preceding break crops and/or may be caused by allelopathic effects from the preceding crops. Finally, the limited areas of lupin plots which did produce a good crop indicated that weed suppression may be taking place in the lupin and following cereal. This phenomenon is not reflected in the results in Tables IX and VII, but was supported in subsequent pot trials and studies by other workers and may therefore be worth further investigation (Robson, 2002).

ECONOMIC SUITABILITY OF BREAK CROPS

Fifteen break crops and oats were assessed in the economic review. The detailed results from this review were submitted to DEFRA in September 1999 in a review entitled " An economic evaluation of potential organic break crops".) The economic evaluation should form part of this final report as Appendix 8.

In selecting a break crop, the practical and direct financial implications must be considered along with the agronomic requirements and effects. The break crop may require specialist machinery and/or labour inputs that are not available on the farm. Marketing must be considered at an early stage. The organic market is currently very fluid, therefore the market should be established before each cash crop is grown. To assess the realistic return to the farm through the inclusion of the different crops in the rotation, net margins were prepared for each crop. As well as the usual gross margin costs and any applicable subsidies, the calculation included field operations, ground preparations, weeding and harvesting based on contractor charges. Even using net margin figures, the direct financial return does not provide a complete economic picture, because the agronomic effects of the crops may be reflected in improved yields of subsequent crops in the rotation.

Twelve of the 15 organic crops in the economic review had positive net margins (based on 1999 prices, including subsidies where appropriate). The desk study showed the effect of strong demand and high prices for organic vegetables for human consumption. Carrot, potato and swede were the most profitable crops for organic systems. Net margins of £6351, £3122 and £3319 ha^{-1} were calculated for highly mechanised organic carrot, potatoe and swede crops respectively. Forage crops and oilseeds, fibre crops and crops requiring processing were less profitable. Where organic processing capacity was not present in the UK, no organic premium was assumed. Following trials by British Sugar in 2000, the predicted net margin for sugar beet of -£198 ha^{-1} (without premium) can be amended to £441 ha^{-1} using average yields and an organic price premium. British sugar offered contracts with an organic price premium in 2001 and 2002.

Materials and methods used in economic assessment of break crops in plot trials

The projected net margins from break crops harvested from the seven plot trials carried out throughout the UK in 1999 and 2000 were calculated using the 1999 prices listed in the economic review. These crops were then ranked in order of their net margin. Total yields were used to calculate the economic returns, since marketable yields were not available for all crops harvested from the trials.

Results and discussion

In terms of economic return to the farmer, carrots returned the greatest profit in four out of seven trials (Table X). Other crops which produced high financial returns included potato and swede, both of which could be sold for human consumption. The market prices shown for all crops are those available in the year that the first of the two trials were run (i.e. 1999). Prices in 2002 may differ, for example, an organic market is now available for sugar beet and providing the crop is grown on contract, good prices can be obtained. Most sugar beet crops made a financial loss in the plot trials when 1999 prices were used. The prices for organic carrots and potatoes have fallen since 1999, but organic carrot and potato production should still be profitable providing crop quality is high and yields are average or above. Hemp, where it was grown and lupin and field bean (where yields were obtained) often gave higher projected net margins than the oats. Oilseed rape would have given much lower net margins than the oat control all seven trials. This was partly due to the fact that there is no developed organic market at present. Linola would have given better returns than oats in five out of the seven trial sites.

Table X Projected net margins from nine break crops and oat grown at seven UK sites

		Net margin[a] (£ ha^{-1})								
Crop	**Price £t^{-1}**	**HRI 1999**	**WIRS 1999**	**HDRA 1999**	**SAC 1999**	**WIRS 2000**	**HDRA 2000**	**SAC 2000**	**Mean**	**Rank (highest net margin = 1)**
F. bean	200	*-201*[b]	*-201*	*-201*	1415	130	*-201*	998	248	6
Carrot	300	5693	3157	3031	495	-39[c]	-293[c]	3157	3107	1
Hemp	60	1329	273	321	45	321	*45*	*45*	340	4
Linola	250	116	428	202	93	415	202	324	254	5
Lupin	175	*110*	*110*	*110*	*110*	286	*110*	315	164	8
O. rape	195	45	3	-33	-3	78	-72	-26	-1	9
Potato	300	443	1507	3027	-924	-469	595	443	660	3
S. beet	35	-264	-330	155	-726	*-361*	-440	-572	-363	10
Swede	225	2361	3730	855	444	*-373*	307	855	1168	2
Oat	140	251	221	361	*81*	295	*81*	281	226	7
Mean		988	890	784	103	32	63	582		

[a]Net margins are based on yields given in Table III and other assumptions outlined in Fowler *et al*. (1999). They have been calculated with assumed receipt of applicable grants and subsidies at English rates and other variable and allocatable fixed costs with field operations assuming use of contractors.
[b]Italics - crop failed, grants and cultivation and seed costs included, no weeding or harvest costs included
[c]Poor crop largely due to competition by weeds. Weeding costs excluded

EVALUATION OF FURTHER DIVERSIFIED ARABLE/GRASS ROTATION

<u>Materials and methods</u>
The above large scale trials were originally designed to include potato, carrot and swede in stocked and stockless rotations. The farmer who had originally agreed to host this part of the project made the decision in 1998 to stop swede production and to remain as a stockless organic farm. It proved impossible to find a single farmer or group of farmers who could host the planned trials on a single soil type/climate area. The results presented below therefore include only potatoes and carrots from a stockless rotation.

Carrot (Nairobi) and potato (Sante) were grown on two separate fields (minimum size 2 ha) in 1998, 1999, 2000 and 2001. A record of the previous three crops was kept for each field prior to the potato/carrot crops being evaluated in this study. Soil was analysed prior to each crop (for major nutrients, trace elements and organic matter content). Diseases, pests and weeds were recorded for each crop once in late summer. Crop nutrient content (major nutrients and trace elements), yield, marketable yield and quality defects were recorded for each crop.

<u>Results</u>
The data on crop and soil nutrient contents is too complex and varied to be included in this short report. It is currently the subject of a MPhil degree by research which aims to develop detailed nutrient budgets for carrot and potato on the farm on which the large scale trials were carried out. The thesis is to be entitled "Development of a system for the large-scale production of organic carrots in north-east Scotland."

The carrot and potato crops in this study suffered from few pest, disease and weed problems apart from late blight (*P. infestans*) in the potatoes which affected all potato crops in each year from between Mid July to Late August onwards. Details of the pests and diseases recorded are noted in Tables XI and XII. Competition from weeds in potato crops was minimised through breaking down the ridges and re-ridging immediately before emergence. Competition from weeds in carrot crops was minimised through the use of stale seedbeds and a flame weeder (Drakedon Ltd.). Hand weeding was also carried out once, approximately 6 weeks after germination of carrot crops. The yield, marketable yield and crop

Table XI Pest and disease problems in carrot crops (variety Nairobi) from large scale field trials near Inverness

Trial	Incidence of pest/disease disease problems recorded at end of August
Field 1, 1998	Slight evidence of carrot fly damage at one side of field
Field 2, 1998	No pest or diseases present
Field 3, 1999	No pest or diseases present
Field 4, 1999	Slight evidence of carrot fly damage in two patches at separate sides of field
Field 5, 2000	Evidence of carrot fly damage at one side of field
Field 6, 2000	No pest or diseases present
Field 7, 2001	No pest or diseases present
Field 8, 2001	Sclerotinia mycelium in foliage in one area of the field

Table XII Pest and disease problems in potato crops (variety Sante) from large scale field trials near Inverness

Trial	Incidence of pest/disease disease problems recorded at end of July
Field 1, 1998	Two plants with blackleg found in field
Field 2, 1998	No pest or diseases present
Field 3, 1999	Late blight (*P. infestans*) now at about 2%
Field 4, 1999	Late blight (*P. infestans*) now at about 1%
Field 5, 2000	No pest or diseases present
Field 6, 2000	Late blight (*P. infestans*) now at about 1%
Field 7, 2001	Late blight (*P. infestans*) now at about 0.5%
Field 8, 2001	Late blight (*P. infestans*) now at about 1%

quality defects for each crop are recorded in Tables XV and XVI in the section on quality and organoleptic characteristics of break crops in plot trials and large-scale trials.

Discussion

The full datasets including information on soil and crop nutrient contents from the above trials are still being analysed as part of a MPhil thesis. Crop quality and yields of carrot and potato from field scale cropping on this commercial organic farm were much higher than those from small scale plot trials run by staff of research associations. For more information, see results in the following section on quality and organoleptic characteristics of break crops in plot trials and large-scale trials.

QUALITY AND ORGANOLEPTIC CHARACTERISTICS OF BREAK CROPS IN PLOT TRIALS AND LARGE-SCALE TRIALS

Materials and methods

All carrots and potatoes from the plot trials in 1999 and 2000 and from the large-scale trials in 1998, 1999, 2000 and 2001 were assessed for quality and organoleptic characteristics. These assessments were made as follows: the percentage of total yield that could be classed as marketable under Tesco's current quality standards for organic carrot and potato crops was assessed for all crops in the plot trials and large scale trials. For the percentage of each crop which was classed as unmarketable, the main quality defects were listed (% of each crop with each defect). A sample of each marketable crop was sent to Dr C Leifert (now of Tesco Centre for Organic Agriculture, Newcastle University) who liased with Tesco food quality and nutrition specialists to organise organoleptic tests. Each crop was classed as acceptable for human consumption under Tesco's current quality standards for organic produce or not acceptable.

Results

The percentage of the total yield of carrots in plot trials which was marketable by current quality standards varied widely between sites (Table XIII). The site in Aberdeenshire run by SAC in 2000 had the lowest percentage marketable yield (17%) and the site in Lincolnshire run by HRI in 1999 had the highest (75%). The most common quality problem across all sites related to root size and shape, but low levels of damage by carrot fly, slug and fungal diseases were also recorded. See the section on effect of break crops on weed, pest and disease incidence in UK field trials for further information.

Table XIII Marketable yield and quality of carrots from break crop trials

			% total yield rejected due to					
Crop	**Yield t ha^{-1}**	**Saleable yield (t ha^{-1})**	**Mis-shapes/ breakages**	**Small size**	**Cavity spot[a]**	**Pest damage[b]**	**Other[c]**	**Eating quality OK ?**
HRI 1999	58	43.5	5	7	4	4	5	Yes
WIRS 1999	38	13.3	12	40	3	7	3	yes
HDRA 1999	37	25.2	10	12	-	8	2	yes
SAC 1999	17	10.2	2	30	-	5	3	yes
WIRS 2000	6	1.9	12	45	2	5	4	yes
HDRA 2000	4	0.8	9	65	-	5	-	yes
SAC 2000	38	6.5	17	52	-	12	2	yes

[a]caused by a complex of organisms including *Pythium* species
[b]caused by slugs and carrot fly
[c]includes diseases caused by *Sclerotinium sclerotiorum* and *Alternaria dauci*

The percentage of the total yield of potatoes in plot trials which was marketable by current quality standards varied between sites but was generally high (Table XIV). The site in Ceredigion run by WIRS in 2000 had the lowest percentage marketable yield (62%) and the sites in Inverness run by SAC in 1999 and in Warwickshire run by HDRA in 2000 had the highest (both 90%). The commonest quality problems across all sites were inappropriate tuber size (usually too small) and tuber blight (caused by *P. infestans*). Losses due to *Erwinia* species and fungal diseases including black scurf, common scab and powdery scab were also recorded. See the section on effect of break crops on weed, pest and disease incidence in UK field trials for further information.

Table XIV Marketable yield and quality of potatoes from break crop trials

			% total yield rejected due to					
Crop	**Yield t ha^{-1}**	**Marketable yield (t ha^{-1})**	**Wrong size[a]**	**Potato blight[b]**	**C. scab[c]**	**Black scurf[d]**	**Other[e]**	**Eating quality OK ?**
Lincolnshire 1999	19	17	2	1	4	2	2	Yes
Ceredigion 1999	26	22	5	7	1	-	3	Yes
Leicestershire 1999	36	32	2	7	-	1	1	Yes
Inverness 1999	10	9	1	6	3	-	-	Yes
Ceredigion 2000	13	8	15	14	3	2	4	yes
Warwickshire 2000	20	18	1	6	1	-	2	yes
Aberdeenshire 2000	19	18	1	2	1	1	1	yes

[a]size unsuitable for retail sales (i.e. too large or too small)
[b]caused by *Phytophthora infestans*
[c]caused by *Streptomyces scabies*
[d]caused by *Rhizoctonia solani*
[e]includes harvesting damage and diseases caused by *Erwinia* species and powdery scab (*Spongospora subterranea*)

The saleable percentage of the total yield of carrots in large scale field trials varied between 79 and 82: this was much higher than in the plot trials (Table XV). The commonest quality problem in all fields was misshapen carrots and carrots broken during harvesting. Low levels of damage by carrot fly, slug and fungal diseases were also recorded.

Table XV Marketable yield and quality of carrot crops (variety Nairobi) from large scale field trials near Inverness

Crop	Yield t ha^{-1}	Saleable yield t ha^{-1}	% total yield rejected due to: Mis-shapes/ breakages	Small size	Cavity spot[a]	Pest damage[b]	Other[c]	Eating quality OK ?
Field 1, 1998	62	50	15	3	-	1	1	yes
Field 2, 1998	73	60	13	2	-	-	3	Yes
Field 3, 1999	65	55	12	1	-	1	1	Yes
Field 4, 1999	71	56	18	2	-	-	1	Yes
Field 5, 2000	75	62	15	1	-	-	2	Yes
Field 6, 2000	73	60	18	-	-	-	1	Yes
Field 7, 2001	79	63	18	-	-	-	2	Yes
Field 8, 2001	65	53	15	-	-	2	1	Yes

[a]caused by a complex of organisms including *Pythium* species
[b]caused by slugs and carrot fly
[c]includes diseases caused by *Sclerotinium sclerotiorum* and *Alternaria dauci*

The percentage of the total yield of potatoes in large scale field trials varied between 88 and 98: this was much higher than in the plot trials (Table XVI). The commonest quality problems in all fields were potatoes of inappropriate size for the intended market (either too large or too small) and tuber blight (caused by *P. infestans*). Losses due to fungal diseases including black scurf, common scab and powdery scab were also recorded. The samples of marketable potatoes and carrots which were sent to Tesco for evaluation were all classed as acceptable under current quality standards for human consumption.

Table XVI Marketable yield and quality of maincrop potatoes (Sante) from large scale field trials near Inverness

Crop	Yield t ha^{-1}	Saleable yield t ha^{-1}	% total yield rejected due to: Wrong size[a]	Potato blight[b]	C. scab[c]	Black scurf[d]	Other[e]	Eating quality OK ?
Field 1, 1998	30	29.5	1	2	1	-	1	Yes
Field 2, 1998	25	22.5	3	3	2	1	1	Yes
Field 3, 1999	28	26.0	2	3	1	-	1	Yes
Field 4, 1999	31	29.8	1	1	-	-	2	Yes
Field 5, 2000	35	32.9	1	2	1	1	1	Yes
Field 6, 2000	32	28.5	3	2	1	1	4	Yes
Field 7, 2001	30	26.4	3	4	1	2	2	Yes
Field 8, 2001	29	26.4	3	3	1	1	1	Yes

[a]size unsuitable for retail sales (i.e. too large or too small)
[b]caused by *Phytophthora infestans*
[c]common scab *Streptomyces scabies*
[d]caused by *Rhizoctonia solani*
[e]includes harvesting damage and diseases caused by *Erwinia* species

Discussion and conclusions

The percentage marketable yields in plot trials tended to be lower than would be normally be expected in field scale production on commercial holdings. Serious pest damage is often seen in plot trials from pests such as carrot fly, slug, rabbit and pigeon, which can cause devastation in the relatively small areas of host plant available to them. However, apart from blight in potato, the main quality problems with both carrot and potato in plot trials related to size and shape of the tubers/roots. It is thought that the small size of tubers/roots was due to both the lack of availability of N (especially with potatoes) and weed competition, which was especially severe where tuber/root size was smallest (e.g. at Aberystwyth, WIRS 1999 and 2000 and at Aberdeenshire, SAC, 2000).

OVERALL DISCUSSION, CONCLUSIONS AND POTENTIAL FOR FUTURE WORK

There are four specific functions that a break crop may perform. These include (i) addition, conservation and cycling of nutrients; (ii) pest and/or disease control; (iii) weed control and (iv) improvement in soil physical characteristics. Each break crop must also have satisfactory yields, be of marketable quality and produce a good economic return.

This project has concentrated on addressing the role of break crops in the second and third of these functions and has also looked at the yield, quality and economic return of the nine break crops in question under UK conditions. There are numerous reports of the beneficial effects of specific break crops on soil structure, but no improvements in soil physical characteristics were recorded following these short trials. Further long term work would be required to establish the effects of different break crops on soil structure.

The way in which the small scale plot trials were set up (with seven separate trials in different areas of the UK) has meant that it is difficult to make genuine statistical comparisons between the crops in the different locations. Initially the intention had been to repeat the first three trials carried out by WIRS, HDRA and SAC in different parts of the same fields. In fact, only the trial run by WIRS in Aberystwyth was repeated in the same field. The decision to site the second Scottish trial in Aberdeen (rather than Inverness) was made due to staffing changes at Aberdeen University which made it difficult to service the site in Inverness. The decision to site the second Midlands trial in Coventry (rather than Leicester) resulted from the fact that the owners of the Leicester site did not have a suitable site for the second trial. Despite the difficulties in comparing results from the seven different trials, a great deal of useful information has been collected from the trials.

There are probably many reasons for the wide differences between break crop performance at the different sites. There were differences in climate, soil type, topography and latitude between sites and these will have affected crop performance (See Appendix 2 for site details). Soil nutrient conditions were shown to be crucial to break crop yield and these varied greatly between sites. The decision was made early on in the life of the project to place the break crops after a cereal crop which was to follow a grass/clover ley. No supplementary nutrients were to be applied prior to any of the test crops. This resulted in many of the break crops being nutrient deficient and yields were depressed. Yields of carrots and potatoes from small scale plot trials were considerably lower than those from field scale commercial crops and the main reason for these yield differences was almost certainly due to the inherent differences in soil fertility.

Pest and disease pressure varied between sites, although where a crop was affected by a serious pest or disease, it was often recorded in all or most sites (e.g. blight in potatoes and chocolate spot in field bean). Some crops were more seriously affected than others. For example, hemp and linola suffered from few pest or disease attacks, yet swede, oilseed rape and potato were badly affected by pests and/or diseases. Pest and disease pressure was probably affected by the proximity of other susceptible crops and by local climate and weather, but it was difficult to assess this fully due to the limited assessments made on crop health.

The impact of break crops on weed burden could not be assessed fully due to the fact that slightly different hand weeding practices were employed in five of the nine break crops at slightly different crop growth stages. However, there is evidence that hemp and linola (which were not weeded after sowing) suppress weeds both during the cropping phase and in the subsequent cereal. Limited additional pot studies and reports showed that lupin may suppress weeds (Robson, 2002). This is an important area of work, but further study is required before it can be confirmed that hemp, linola and lupin can have a practical role in weed suppression and control in organic rotations. It was originally intended to rank the nine tests break crops in order according to their agronomic potential. Following the experimental work, it was decided that such an overall rank would be meaningless given the wide variation in crop performance between sites and soils. It would be possible to rank individual break crops in terms of different properties such as weed suppressing ability, soil structural effects etc. This possibility will be discussed in the proposed refereed paper (see Appendix 6).

The net margins for the nine break crops and oats were calculated with the data obtained in the "Economic evaluation of potential organic break crops" which was supplied to DEFRA in 1999. It is likely that if 2002 figures for production costs and market prices were used, carrot, potato and swede would still be the most profitable crops. However, there are now organic premiums available for oilseed rape and sugar beet, so those crops would be more profitable than Table X suggests. The economic returns for oat in the small scale plot trials were low because oat grew and yielded poorly. Higher returns are likely on commercial organic farms.

The yields obtained in small scale plot trials varied greatly in comparison to the average yields quoted for organic crops in the "Economic evaluation of potential organic break crops". Most were much lower, but a few were higher. Many of the farms which are now converting to organic status have in the past been highly successful, modern, large scale conventional operations. The limited evidence which is available so far (W. Rose, K. Barnard, TIO Ltd., pers. comm) suggests that yields from crops on these newly converted organic farms are often considerably higher than the established average yields of organic crops. The results from the evaluation of further diversified arable/grass rotations supports this theory: total yields of up to 35 t ha^{-1} (potato) and up to 79 t ha^{-1} (carrot) were obtained in field scale trials on a commercial organic farm. These yields are 25% higher (for potato) and 106 % higher (for carrot) than those estimated in the initial "Economic evaluation of potential organic break crops".

The percentage of total yield which was marketable was much higher in the commercial organic crops than in the small scale plot trials. This was as expected. The large scale trials were carried out on a farm which specialises in organic carrot and potato production. The entire production system was dedicated to only two crops and the livelihoods of the farm staff were dependent on these crops. On the other hand, research teams running the small scale plot trials had to grow and look after ten different break crops in addition to other research commitments. Organic production (particularly horticultural production) is becoming increasingly specialised, and increasingly dependent on modern technologies, therefore total yields and marketable yields are expected to continue rising in the near future as organic crop husbandry methods improve.

Main conclusions from project

- Yields of individual break crop varied greatly between the seven different trials
- Break crop yields were strongly correlated with soil nutrient concentrations
- Cereal yields were affected more by soil fertility status than by preceding break crop
- Over 50% of break crops were deficient in N, P and/or K (according to established values for nutrient concentrations for healthy crops) with N deficiency being the most common. Subsequent cereal crops mostly had adequate nutrient concentrations, although some were deficient in trace elements
- Break crops suffered varying degrees of pest and disease pressure. Hemp and linola had almost no recorded pest/disease damage at any site. Swede, rape and potato were severely affected by pests and/or diseases on most sites
- Different weed burdens were recorded in different break crops. Limited meaningful conclusions can be drawn from this result for five of the crops tested (bean, carrot, potato, swede, sugar beet), due to the different weed control practices at different trial sites on these crops.
- Significantly lower weed burdens were recorded in cereals following hemp and linola.
- The break crops with the highest potential net margin grown in this study were carrot, swede and potato.
- The break crops with the lowest net margins based on 1999 prices were sugar beet and oilseed rape (osr price included an assumed 50% organic premium); organic premiums are now (2002) available for sugar beet.
- Crop quality and yields (and therefore economic returns) from carrot and potato from field scale trials run on a commercial organic farm were much higher than those from small scale plot trials
- All samples of marketable crop (carrot and potato) from the small scale plot trials and field scale trials were classed as acceptable for human consumption under Tesco's current quality standards for organic produce.

Summary of properties of the nine test break crops

Carrot - A crop with very high economic potential but which needs careful attention to weed control if yields are to be maximised. The main potential pest problem which could seriously affect yield is carrot fly. Has a low demand for N and moderate to high requirement for P and K.

Potato - A crop with very high economic potential but also a high risk crop due to the potential for late blight blight to cause high crop losses or total crop failure in some years. The difficulties of controlling blight in potatoes may become much worse when EU approval for copper use is revoked. Other problems including potato cyst nematode, black scurf, powdery and common scab may become more prevalent due to the use of fully organic seed. Has a moderate to high demand for N, P and K.

Swede - A crop with very high economic potential but also a high risk crop due to the potential for attack by a range of pests (including root flies, caterpillars and flea beetle) and diseases (including alternaria, mildew etc.). Has a moderate requirement for N, P and K.

Field bean - Provides good economic returns if average or better yields are obtained. However crop failure and crop losses were common in this project due to pest and disease damage, therefore it is probably a risky organic crop on some sites. No N or P required. Has low K requirements.

Linola - A crop with reasonable economic returns providing average yields are obtained. A useful break crop since it is unrelated to all other common agricultural crops and suffers from no diseases or pests other than birds. Has low N and P requirements and moderate K requirements.

Lupin - Provides reasonable economic returns if average or better yields are obtained. Crop failure was common in this project, but that is probably unusual. The crop suffered from few pests and diseases when growing. Has no N requirements and low requirements for P and K.

Oilseed rape - There is little potential for organic oilseed rape production at present, since the economic returns are low and the risk of loss of crop quality and yield due to many potential pest and disease problems is high. Other oilseed crops, such as linola and sunflower are probably better suited to organic production. Has a high N requirement and low to moderate requirements for P and K.

Hemp - A crop with very low economic potential. However, the limited evidence from practical work and literature reviews associated with this project suggests that it may provide valuable break crop functions in relation to weed control and effects on soil structure. More work is required. Has medium to high requirements for N, P and k.

Sugar beet - The economic potential has improved following the establishment of an organic market. The crop requires careful management to control caterpillars in some sites. Has low requirements for N, P and K.

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